



# GPS Civil Applications



## GPS Integrity Failure Modes and Effects Analysis (IFMEA)

**CGSIC Meeting  
Sept. 27, 2004**

**Karen Van Dyke  
DOT/Volpe Center  
vandyke@volpe.dot.gov**



# GPS Civil Applications



## Overview

- What is IFMEA?
- What Capability Does it Provide?
- Why is it Important?
- How Should This Capability Be Used?
- Does Your Organization Need This Capability?



# GPS Civil Applications



## Introduction

- **Desire to rely on GPS for safety of life applications worldwide**
- **Service meets specified levels**
  - **Accuracy, availability, continuity, and integrity**
- **Standalone GPS cannot meet integrity requirements**
  - **Augmented GPS required (RAIM/FDE, Differential-Based Systems)**
- **Knowledge of GPS Failure Modes Required to Design Integrity Monitoring Systems**



# GPS Civil Applications



## What is IFMEA?

- Integrity Failure Modes and Effects Analysis (IFMEA) project established by IGEB
  - 3-year project started in April 2002
  - Follow on to work done by JPO in 1990's
  - Interagency initiative
  - Team consists of DOT, JPO, and contractors
- Based on previous GPS failure studies, SV and OCS system design descriptions, and operational procedures



# GPS Civil Applications



## Background to IGEB IFMEA Project

- Block I/II/IIA SV and OCS Integrity Aberrations Identified, Catalogued, and Updated By GPS JPO and Support Contractors From 1988 Through 1998
- GPC Recognition That Similar Work Had Not Been Conducted for Block IIR, IIRM, IIF, and AEP
- IGEB IFMEA Project Initiated to Develop Aberration and Update Block II/IIA Work and Provide Recommendations for GPS III
- Process Required to Sustain ACS Process After IGEB Stewardship Funds



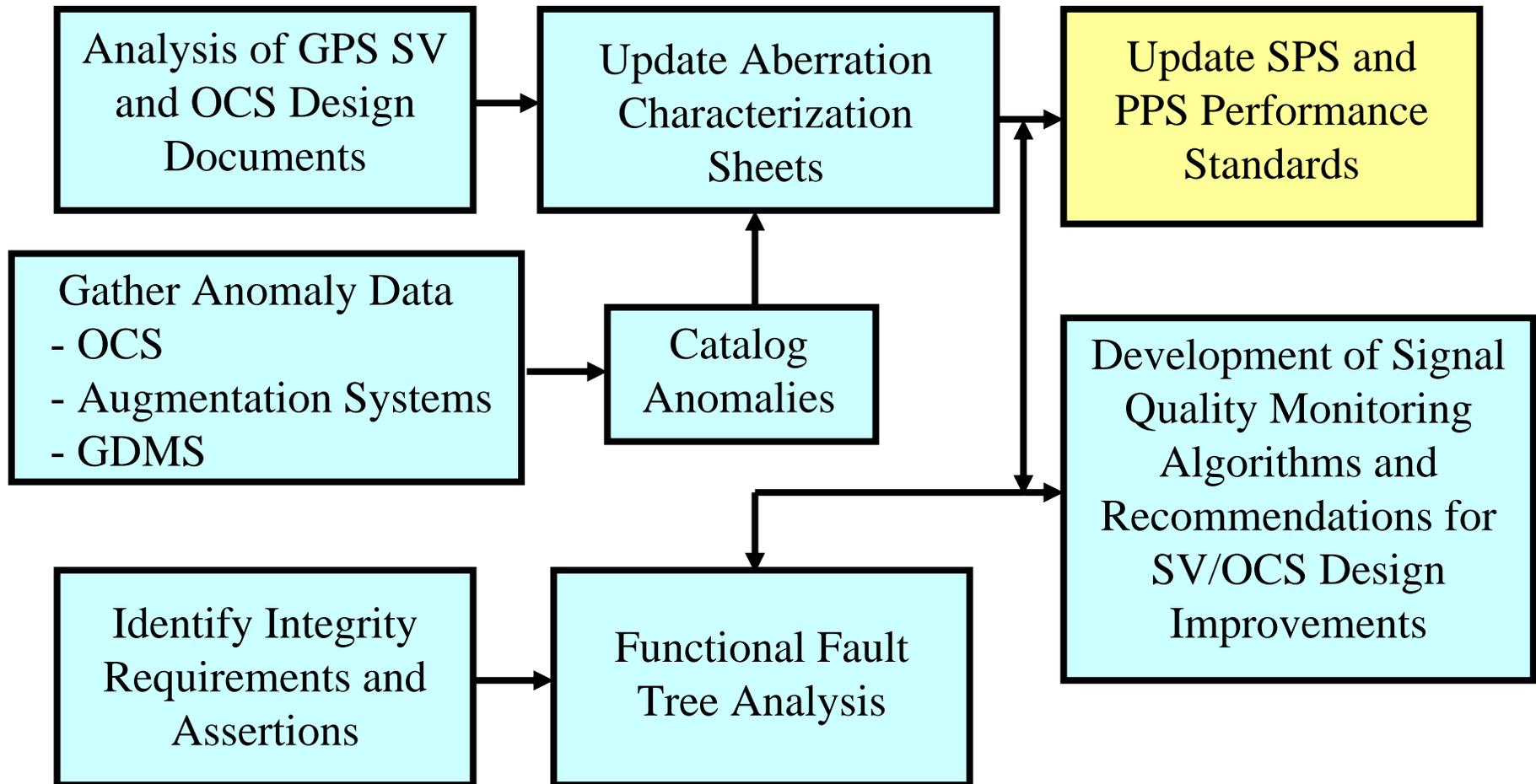
# GPS Civil Applications



## IFMEA Objective and Benefits

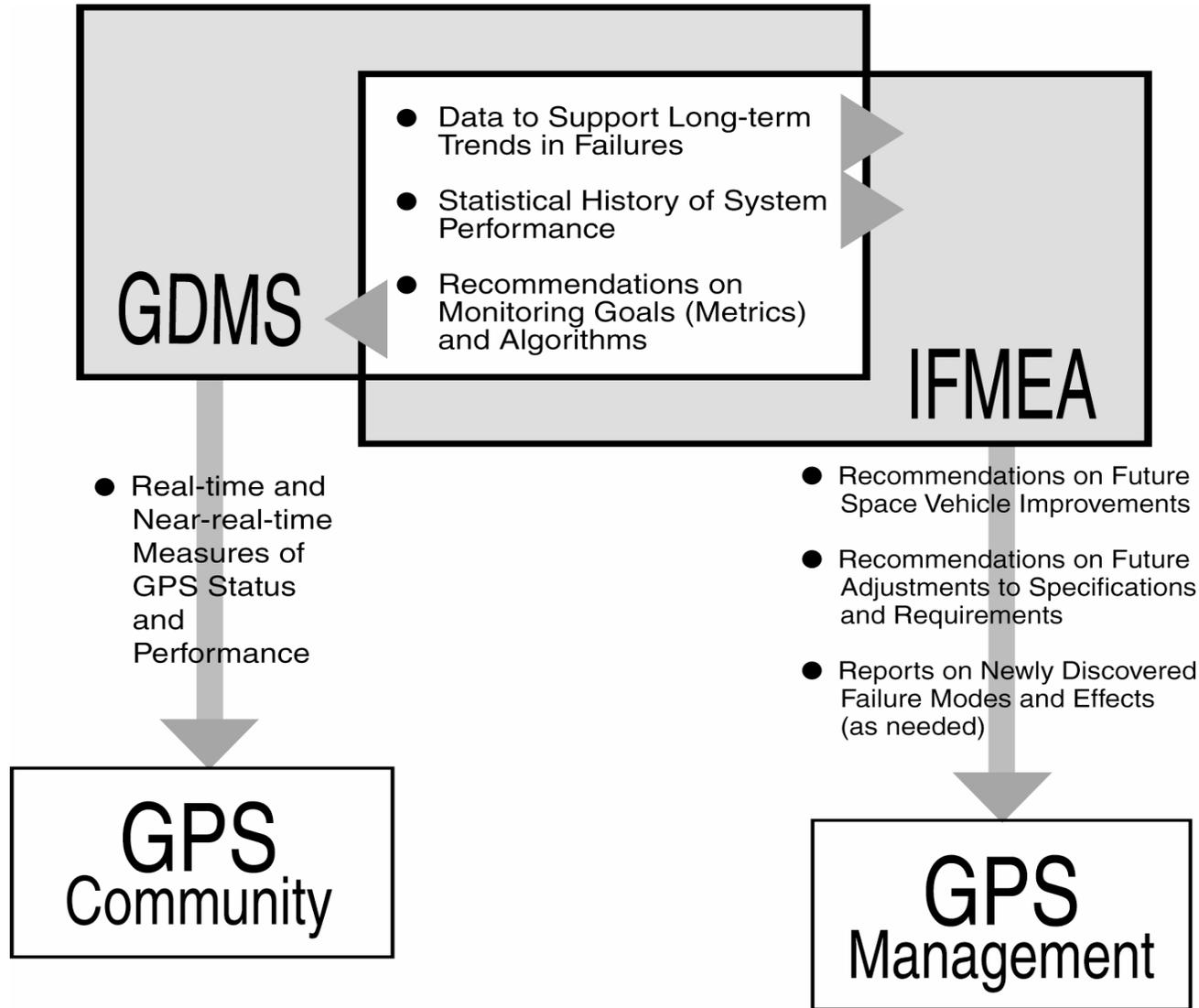
- Identify GPS integrity anomalies (SV and OCS), potential causes and operational impacts of failures
  - Determine probability of individual failure modes (theoretical and observed)
- Develop interagency definition of GPS integrity parameters to perform effects analysis
- Improve the reliability of GPS in the future by providing recommendations of
  - GPS SV and OCS design modifications
  - Integrity monitoring provided by civil/military augmentation systems and monitoring networks
- Increase user confidence in the ability of GPS satellites and OCS to satisfy requirements stated in performance standards

## IFMEA Process Flow Diagram





# GPS Civil Applications





# GPS Civil Applications



## Aberration Characterization Sheet (ACS)

- Identifies failure points that could affect integrity
- Uses failure studies (e.g., FMECA) and system descriptions (e.g., wiring and block diagrams) provided by manufacturer
- ACSs previously developed for Block I, Block II, Block IIA, and Legacy OCS
- Project is developing ACSs for Block II-R, Block IIRM, Block IIF, and Architecture Evolution Plan (AEP) OCS and Updating Block II/IIA and Legacy OCS



# GPS Civil Applications



## Aberration Characterization Sheet (ACS)

<b>ABERRATION NAME:</b> Name Assigned to Aberration	
<b>SEGMENT ALLOCATION:</b> System, Space, Control, User	
<b>SHORT DESCRIPTION:</b> What is the aberration?	
<b>PROXIMATE CAUSE(S):</b> What most directly causes the aberration?	
<b>PRECIPITATING EVENT(S):</b> What is the ultimate source of the aberration?	
<b>PROBABILITY OF OCCURRENCE:</b> Per day, per year, per SV, per constellation, per upload	<b>EFFECT/MAGNITUDE:</b> Effect on signal: Off, nil, ramp, step, noise, sinusoid, m, m/sec, m/sec squared
<b>DETECT RESPONSIBILITY:</b> System, Space, Control, User, mix, none  When an aberration occurs, who is responsible for determining that it happened?	<b>UNDETECTED PROBABILITY:</b> Per day, per year, per SV, per constellation, per upload  Probability that the aberration goes undetected.
<b>POST-DETECT EFFECT/MAGNITUDE:</b> Off, nil, ramp, step, noise, sinusoid, m, m/sec, m/sec squared  What happens after the aberration has been detected?	<b>UNDETECTED DURATION:</b> Time until aberration is detected and user notified.
<b>REPRESENTATIVE OCCURRENCES (IF ANY):</b> Based on observed data obtained through IFMEA data collection effort	



# GPS Civil Applications



## Development/Update of Aberration Characterization Sheets

- Team developed ground rules for preparing, maintaining and updating ACS sheets.
- Ten books written by Lockheed Martin on Block IIR Failure Modes And Effects Criticality Analysis Report (FMECA) were reviewed by the team members.
  - Aberration Characterization Sheets (ACSs) were written by team members on the failure modes listed in the IIR FMECA to identify integrity anomalies.
  - 53 anomalies identified and incorporated into the existing ACS Book.
  - Updates to the ACS Book included integrating Block II/IIA material with Block IIR.
- On-orbit Block IIR SV Incident Reports (SVIRs) incorporated into the ACS Book.



# GPS Civil Applications



## Focus of Recent IFMEA Activity

- **Documentation Identification for Block IIRM, IIF, and AEP ACS Development**
- **Development of Block IIF ACSs**
- **Functional Fault Tree Analysis**
- **Review of Legacy OCS Procedures**
- **WAAS ACS Effects Analysis**
- **SQM Analysis**
- **Development of GPS Integrity Anomaly Database**
- **Recommendations for GPS III**
- **Development of IFMEA Transition Plan**



# GPS Civil Applications



## 2004-2005 IGEB IFMEA Project

- Prepare for Transition of IFMEA Processes Over to GPS JPO for Long-Term Updating and Maintainability
  - Update Aberration Characterization Sheets Through Block IIF SVs and AEP
  - Integrity Anomaly Database Available for Use (Public and Secure Versions)
  - Finalize Recommendations for Integrity Monitoring and SV/OCS Design Constraints or Improvements
  - Develop Processes, Procedures, and Training for Continuation of IFMEA Work Without Stewardship Funds



# GPS Civil Applications



## Block IIR Time Keeping System

- IIR/IIR-M Satellites Do Not Have Clock Run Off Errors
  - Run two clocks concurrently
    - Atomic (Rubidium)
    - VCXO (Quartz)
  - Monitor short-term difference between the clocks
    - If difference greater than a threshold (~5 m)
      - Immediately switch to non-standard code



# GPS Civil Applications



## Nominal Signal Deformation – Code Domain

Possible Explanation for Measured Signal Distortion Observed  
By Honeywell and Stanford

- Suspected that lead/lag distortion caused by asymmetries in rise/fall times of switching logic onboard the satellites
- ITT\* confirmed that this is the likely cause
  - No current requirement for symmetry (they do not control this parameter)
  - Attempt to keep difference within 1% (~10ns)
  - Surprised by large asymmetry on IIRs
  - Modulator on IIAs and IIRs use the same technology
- Suggested pre-launch SV testing of SVs to characterize biases

\*ITT is responsible for building some of this signal generating hardware for Block IIAs, IIRs



# GPS Civil Applications



## GPS Integrity Anomaly Database (GIAD)

- Key features
  - Includes both anomaly and aberration databases
    - Anomaly database stores anomaly type, satellite number, satellite block affected, magnitude of error, and duration
    - Aberration database stores aberration data per ACS
  - Anomaly database tied to Aberration database for updating
  - Web-based
  - Easy lookup features
    - Synonyms – wider searches without having to enter all keywords





# GPS Civil Applications



## Login Screen

IFMEA Anomaly Database - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

https://10.10.10.122/anomalydb/cgi-bin/do\_index.pl

### IFMEA Anomaly Database User Login

**Site Directory**

- [Search Anomalies](#)
- [Search Anomalies \(Detailed\)](#)
- [Browse Aberrations](#)
- [Browse Anomalies](#)
- [Browse Contacts](#)
- [Enter an Aberration](#)
- [Enter an Anomaly](#)
- [Generate Statistics](#)

**Please enter your username and password**

(Use 'guest' and your email for guest access)

Username:

Password:  Your Overlook-assigned username:

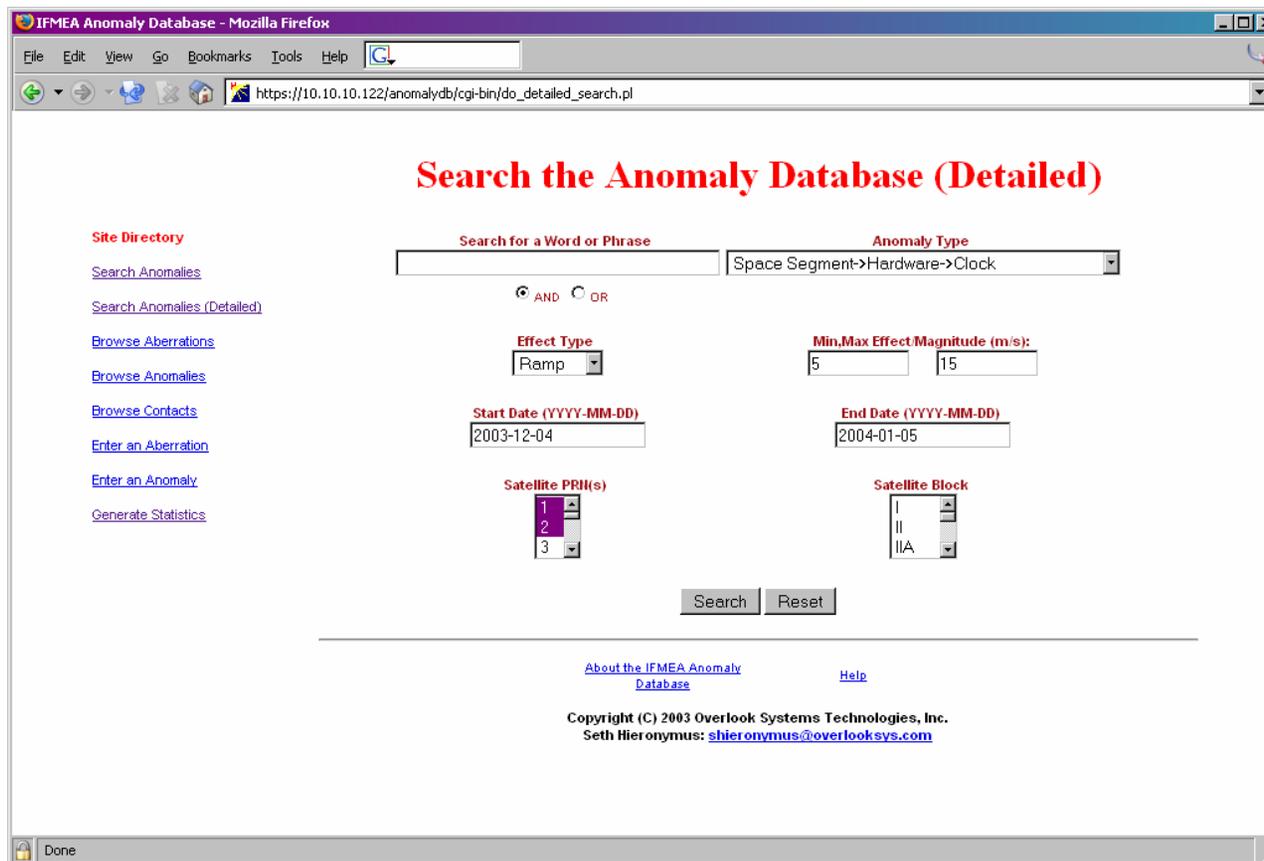
---

[About the IFMEA Anomaly Database](#)      [Help](#)

Copyright (C) 2003 Overlook Systems Technologies, Inc.  
 Seth Hieronymus: [shieronymus@overlooksys.com](mailto:shieronymus@overlooksys.com)

Done

## Detailed Search Screen



IFMEA Anomaly Database - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

https://10.10.10.122/anomalydb/cgi-bin/do\_detailed\_search.pl

### Search the Anomaly Database (Detailed)

**Search for a Word or Phrase** **Anomaly Type**

AND  OR

**Effect Type** **Min,Max Effect Magnitude (m/s):**

**Start Date (YYYY-MM-DD)** **End Date (YYYY-MM-DD)**

**Satellite PRN(s)** **Satellite Block**

[About the IFMEA Anomaly Database](#) [Help](#)

Copyright (C) 2003 Overlook Systems Technologies, Inc.  
Seth Hieronymus: [shieronymus@overlooksys.com](mailto:shieronymus@overlooksys.com)

Done



# GPS Civil Applications



## Browse Anomaly Screen

IFMEA Anomaly Database - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

https://10.10.10.122/anomalydb/cgi-bin/browse\_incidents.pl?Record=2

### Browse the Anomaly Database

**Site Directory**

- [Search Anomalies](#)
- [Search Anomalies \(Detailed\)](#)
- [Browse Aberrations](#)
- [Browse Anomalies](#)
- [Browse Contacts](#)
- [Enter an Aberration](#)
- [Enter an Anomaly](#)
- [Generate Statistics](#)

File Attachments:

[Printable Version](#)

**Anomaly Record Number:**  **Anomaly Name:**

**Primary Aberration Code:**

**Secondary Aberration Code(s):**

<b>Start Date (YYYY-MM-DD):</b>	<b>Start Time (HH:MM:SS):</b>	<b>End Date (YYYY-MM-DD):</b>	<b>End Time (HH:MM:SS):</b>
<input type="text" value="2004-01-01"/>	<input type="text" value="18:33:00"/>	<input type="text" value="2004-01-01"/>	<input type="text" value="21:18:00"/>

<b>Duration (hrs):</b>	<b>Effect Type:</b>	<b>Effect Magnitude (m/s):</b>	<b>PRIs:</b>
<input type="text" value="2.75"/>	<input type="text" value="Ramp"/>	<input type="text" value="70.2"/>	<input type="text" value="23"/>

**Description:**

A significant GPS anomaly occurred on 1 Jan 04, beginning at approximately 1833Z. The anomaly affected precise timing and navigation users over large portions of Europe, Africa, Asia, Australia, and the far northern reaches of North America.

**Contact:**

[About the IFMEA Anomaly Database](#)      [Help](#)

Copyright (C) 2003 Overlook Systems Technologies, Inc.

Done



# GPS Civil Applications



## Browse ACS Screen

IFMEA Anomaly Database - Mozilla Firefox  
 https://10.10.10.122/anomalydb/cgi-bin/browse\_aberrations.pl?Record=31

### Browse the Aberration Database

[Printable Version](#)

**Aberration Record Number:** 31 **Aberration Code:** II.E.2

**Aberration Name:** Phase Run-Off (Clock Failure, Atomic, Electronics)

**Anomaly Category:** Space Segment->Hardware->Clock

**Short Description:** SIS code phase run-off due to a failure in an atomic clock's electronics.

**Proximate Cause(s):** SV frequency bias

**Precipitating Event(s):** Atomic clock electronics failure

**Probability of Occurrence:** 1.1 E-2 per SV per year **Effect Magnitude:** RAMP, 10 m/hr

**Detect Responsibility:** Control **Undetected Probability:** 0.00\*

**Post-Detect Effect Magnitude:** OFF, N/A **Undetected Duration:** 1.5 to 4.0 hr\*

**Representative Occurrences (if Any):** 2: Failed Atomic Frequency Standard - SVN23

**Remarks:** \* Detection probability by OCS is near 1.00 after the long non-detection period. The non-detected period is a function of the OCS design and of the means chosen to alert the users not to use the particular SV.

[About the IFMEA Anomaly Database](#) [Help](#)

Copyright (C) 2003 Overlook Systems Technologies, Inc.  
 Seth Hieronymus: [shieronymus@overlooksys.com](mailto:shieronymus@overlooksys.com)



# GPS Civil Applications



## Search Results Screen

IFMEA Anomaly Database - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

https://10.10.10.122/anomalydb/cgi-bin/search\_by\_fields.pl?Statistics=1

### Search Results

**Site Directory**

- [Search Anomalies](#)
- [Search Anomalies \(Detailed\)](#)
- [Browse Aberrations](#)
- [Browse Anomalies](#)
- [Browse Contacts](#)
- [Enter an Aberration](#)
- [Enter an Anomaly](#)
- [Generate Statistics](#)

**Search Conditions: All records that contain the word(s): atomic**

---

<b>General: Aberration Code</b>	<b>Number Anomalies</b>
I.E.2	1
<b>Total</b>	<b>1</b>

<b>Satellite Block</b>	<b>Number Anomalies</b>
I	0
II	0
IIA	1
IIF	0
IIR	0
IIR-M	0
<b>Total</b>	<b>1</b>

<b>Effect/magnitude: EffectType</b>	<b>Min Magnitude</b>	<b>Max Magnitude</b>	<b>Avg Magnitude</b>	<b>Std Magnitude</b>
Ramp	70.20	70.20	70.20	0.00

<b>Duration (hrs):</b>	<b>Min Duration (hrs):</b>	<b>Max Duration (hrs):</b>	<b>Avg Duration (hrs):</b>	<b>Std Duration (hrs):</b>
	2.75	2.75	2.75	0.00

[Export to a File](#)

---

[About the IFMEA Anomaly Database](#)
[Help](#)

Copyright (C) 2003 Overlook Systems Technologies, Inc.  
 Seth Hieronymus: [shieronymus@overlooksys.com](mailto:shieronymus@overlooksys.com)

Done



# GPS Civil Applications



## Access to Database Prototype

- URL: <https://216.150.201.34>
- Username/password: betatest/ifmea
- Username/password: guest/<email>
- Project contact: John Lavrakas,  
[jlavrakas@overlooksys.com](mailto:jlavrakas@overlooksys.com)
- Technical contact: Seth Hieronymus,  
[shieronymus@overlooksys.com](mailto:shieronymus@overlooksys.com)
- Database Administrator: Brian Carroll,  
[bcarroll@overlooksys.com](mailto:bcarroll@overlooksys.com)



# GPS Civil Applications



## WAAS Effects Analysis

- IFMEA team requested to validate the WAAS assertions against the Aberration Characterization Sheets (ACSs)
- The team has focused on the following:
  - WAAS Assertions
  - RAIM and WAAS/RAIM Assertions
  - GPS/Inertial Assertions



# GPS Civil Applications



## WAAS Effects Analysis

- **Current analysis performed with the “Block II” version of the ACS**
- **Results must be updated when the Block IIR update is complete**
- **WAAS assumptions affected by not aberrations not monitored by Control Segment**
- **Statistics**
  - 82 ACSs
  - 25 ACSs affect at least one assertion
  - 11 WAAS Assertions
  - 3 RAIM Assertions
  - 3 GPS/Inertial Assertions

ABERRATION CHARACTERIZATION SHEET (ACS)  
III.C.4

<b>ABERRATION NAME:</b> Bad SV Tracking Data: Noisy 50 Hz Data (NAV Message)	
<b>SEGMENT ALLOCATION:</b> Control Segment (MS)	
<b>SHORT DESCRIPTION:</b> An MS's SV tracking data for the 50 Hz NAV message can be noisy in a manner exactly analogous to the UE. Erroneously received settings for bit 18 of the HOW can cause unexpected reactions. Other bits produce no resulting effect.	
<b>PROXIMATE CAUSE(S):</b> Erroneously decoded bit 18 of the HOW	
<b>PRECIPITATING EVENT(S):</b> SIS path environment, noisy DEMOD hardware, low C/No	
<b>PROBABILITY OF OCCURRENCE:</b> 1.00 per SV per year	<b>EFFECT/MAGNITUDE:</b> OTHER, OTHER
<b>DETECT RESPONSIBILITY:</b> Control (MCS)*	<b>UNDETECTED PROBABILITY:</b> 4.2 E-16
<b>POST-DETECT EFFECT/MAGNITUDE:</b> OTHER, OTHER**	<b>UNDETECTED DURATION:</b> 1.5 to 4.0 hr
<b>REPRESENTATIVE OCCURRENCES (IF ANY):</b> SVN 13 (Block II, PRN-13), September 1989; two occurrences only	
<b>REMARKS:</b> * Detection is by Hamming parity and by operator visual monitoring. ** Post-detect effect/magnitude details not releasable.	



# GPS Civil Applications



## Summary

- IFMEA Project Provides Better Understanding of Integrity Anomalies and Probability of Occurrence
  - Development of Improved Integrity Monitoring Algorithms
  - Recommendations for Improved Future GPS SV and OCS Design
  - GIAD will Support Analysis of Anomalies
- Need to Have Smooth Transition of IFMEA Project/Process to GPS JPO with Continued Civil Participation